Who gains from computer use?

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Since the 1980s, wage inequality between highly educated and less educated workers has grown substantially. One hypothesis is that the computerization of work allows workers to shift their focus from routine tasks to problem solving, and that this 'upskilling' increases productivity and wages (Attewell 1987). One study found that workers who used a computer on the job earned 17.6% higher wages than those who did not (Krueger 1993). This paper sparked debate as to whether the return is truly for using a computer or a result of being selected to use one. If workers with high ability or unobserved skills are those given computers on the job, then cross-sectional results could falsely attribute a wage premium to computer use—a conclusion supported by a study finding that workers who used other tools associated with white-collar type work, including a pencil and a hand calculator, received a similar return on these tools (DiNardo and Pischke 1997).

A few researchers have used panel data to control for unobserved individual differences. Most found small or insignificant returns on technology use, suggesting that firms are allocating information technologies to their highest skilled workers, who already earn more.

While proponents of upskilling argue that computerization can lead to productivity and wage increases, critics counter that computerization can be *de*skilling. That is, the increased mechanization reduces workers' control over the production process and simplifies jobs, leading to lower wages. In fact, the introduction of new technology may be upskilling for some workers (because it complements them in production) and deskilling for others (because it substitutes for them in production), even within a single firm. A case study of the introduction of digital cheque imaging in a bank, found that exceptions processors spent more time on problem solving and less on repetitive tasks while the staff of deposit processors with the same skill requirements was reduced (Autor, Levy, and Murnane 2002). In this case, computers substituted for some routine tasks and complemented problem-solving. These differences may be observable between occupational groups as computers change skill requirements. For example, word-processing programs may be deskilling for clerical workers because documents can be prepared more quickly and with fewer skills, but upskilling for managers because such programs allow them to take on a greater variety of tasks. Another reason for differential returns to technology across workers is that managers and professionals with high cognitive skills are especially important for the implementation of new technologies (Bresnahan, Brynjolfsson and Hitt 2002). They need to be able to transform organizations to take advantage of technology and new information so that they can learn about their customers. Similarly, since highly educated workers have a comparative advantage in adjusting to new technologies, the introduction of new technologies should shift demand away from less educated workers (Bartel and Lichtenberg 1987).

This study uses a panel of workers surveyed in the 1999 and 2000 Workplace and Employee Survey (WES) to re-examine wage premiums for using a computer at work (see *Data source*). It identifies the return to adopting a computer, as distinct from the negative return from ceasing to use a computer, and examines the returns for specific subgroups of workers by education, occupation, and computer application. It also measures the longer-term returns to continued computer use and the effects of previous computer experience and training to determine whether the difference between the small returns for adopters and the much larger returns for continued users can be attributed to learning costs.

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Wage differential for computer use

A 'naïve' wage equation was estimated by ordinary least squares with various personal characteristics and computer use (yes/no) as the explanatory variable of interest (see *Methodology*). The resulting wage premium for computer use is 16.9%, which does not account for selection effects or differing effects across subgroups of workers (Table 1).

Unobserved worker characteristics, such as ability, may also make computer users different from other workers. If these unobservables are correlated with wages,

Table 1 The wage effect of using a computer

	Pooled OLS model (naïve)	Individual fixed-effects model	First-differenced model
Dependent variable	ln(hourly $)	ln(hourly $)	Δln(hourly $)
Computer user	.1565***	.0160**	...
Both years (maintainers)	...	...	.0375***
1999 only (ceasers)	...	...	.0029
2000 only (adopters)	...	...	.0377***
R^2	0.4285	0.0879	
Adjusted R^2			0.0243

Source: Workplace and Employee Survey, 1999 and 2000
*Statistically significant at * = p<.10; ** = p<.05; *** = p<.01.*
Note: The OLS model includes a constant, years of education, potential experience (and its square), parents or grandparents from a non-European country, different language at work than at home, part-time status, marital status, sex, sex interacted with marital status, union coverage, regional indicators, five occupational indicators, tenure with the establishment, a year indicator, the natural log of establishment size, and the percentage of computer users in the establishment. The other models include the same variables except those that are constant over time and recent promotion in 2000.

Methodology

An economic model of wages that accounts for the production activities of firms, employee education, varying employee productivity, varying job complexity across occupations, declining computer costs and varying computer training costs results in four possible sources of wage dispersion relating to computer use and adoption (Zoghi and Pabilonia 2004).

1. Computer users might be more productive relative to non-users, regardless of computer use.
2. Computer users might be the type of employee firms protect by paying higher-than-market (or efficiency) wages.
3. Higher computing productivity might raise wages for computer users.
4. Lower costs of computerization might increase the computer wage premium.

Only the third source represents the 'true' computer wage premium. The others indicate that computer use probably coincides with other employee characteristics that employers value (selectivity effects). This study uses a number of different approaches to isolate the true computer wage premium from the selectivity effects.

Cross-sectional ordinary least squares (naïve)
This model estimates the gross wage differential between computer users and non-users that includes all four factors outlined above, controlling for years of education, potential experience, potential experience squared, parents or grandparents from a non-European country, different language spoken at work than at home, part-time status, marital status, sex, sex interacted with marital status, union coverage, regional indicators, five occupational indicators, tenure with the establishment, a year indicator, establishment size, and percentage of computer users in the establishment.

Controlling for unobserved qualities
If computer users have other unobserved qualities (such as ability or ambition) that are correlated to wages, then cross-sectional estimates of the computer wage premium, as above, are upward biased. However, an algebraic trick can be used with panel data to eliminate this bias. If wage changes are estimated as a function of the change in characteristics over time, then all characteristics that do not change (whether observed or unobserved) 'drop out' of the model. These are termed 'fixed-effects' models. Only those characteristics that can change over time are included: education, potential experience, marital status, work-home language differences, part-time status, union coverage, job promotion, number of employees, and the percentage of computer users within the establishment.

Since the returns to computer use can also vary according to changes in computer use patterns, the four possible computer use transitions a worker can experience over time can be separately identified, and returns to computer use allowed to vary between these groups of individuals and over time. The four transitions are those who never used a computer, those who used a computer in both periods, those who ceased using a computer in 2000, and those who adopted a computer between 1999 and 2000.

An alternative approach is to use past wages to capture the fixed effect. This enables the return to computer use of long-term users to be estimated, as opposed to focusing on changers.

Since the theoretical model also indicated that the computer-use premium could vary by type of worker and application, all the fixed-effects models were estimated separately by occupational groups, educational groups, and application used most frequently. Computer training variables were added to examine the interactions between training and the computer wage premium.

the previously reported wage premium would be incorrectly attributed to computer use. Indeed, many other researchers have found that the wage premium for computer use is greatly diminished or no longer exists when they control for unobserved individual heterogeneity.[1] Many demographic variables are time-invariant and consequently do not appear in the fixed-effects model. However, education did change for quite a few workers, possibly due to measurement error in one or both years. Additionally, marital status, work-home language differences, part-time status, and union coverage can change. For many of the establishments, both the number of employees and the percentage of computer users changed between 1999 and 2000. Also considered was recent promotion, a factor that may be correlated with changes in both computer use and wages.[2]

Confirming previous results, the fixed-effects estimate was only 1.6% (Table 1, column 2).[3] Identification in this specification comes from the 9% of workers who changed computer status—6% adopted and 3% ceased to use a computer in 2000.[4] The model assumes the absolute value of the return to computer use is the same for both adopters and ceasers—which may not be the case. In addition, it does not provide any information about the return to computer use for workers who used a computer in both 1999 and 2000 or even for many years prior to 1999 (Dolton and Makepeace 2004).

Therefore, the four possible computer-use transitions a worker can experience over time were separately identified, and returns to computer use were allowed to vary between these groups of individuals and over time. The four transitions are: those who never used a computer, those who used a computer in both periods, those who ceased using a computer in 2000, and those who adopted a computer between 1999 and 2000.

In a first-differenced model, the effect of computer use on wages for the average worker in the first year of computer adoption is a statistically significant 3.8% (Table 1, column 3). The coefficient on ceasing to use a computer is not statistically significantly different from zero, perhaps due to downward wage rigidity.

The small wage premium found does not necessarily indicate that returns to computer use are this small but merely that returns to the average worker in the first year of computer use are small. Returns might be small in the first year if employers passed along some or all of the costs of computer training to their employees. However, the return to long-run computer experience for continuing computer users may well differ.

Accounting for worker differences and technology use

So far, the implication has been that the average worker does not earn the high wage premiums initially associated with computers—at least in the short

Data source

The **Workplace and Employee Survey** was initially conducted in 1999. Establishments in the survey are followed annually, while employees are followed for only two years and then re-sampled. The analysis used a panel of employees with their matched employer information from 1999 and 2000—the most recent available. The panel aspect allows a control for unobserved individual characteristics that might affect the propensity for computer use as well as wages.

In 1999, more than 23,500 employees in almost 6,000 establishments were interviewed. Establishments were first selected from employers with paid employees in March of the survey year. Employers in the territories and those operating in crop and animal production; fishing, hunting, and trapping; private households; religious organizations; and public administration were excluded. At each establishment, a maximum of 24 employees were randomly sampled. All employees were selected in establishments with fewer than four employees. In 2000, just over 20,000 employees were re-interviewed. For some of the main econometric analysis, a restricted sample was used—the 19,000 employees who responded in both years, remained with the same employer in both years, and had non-missing observations on the dependent and independent variables. (No significant differences were apparent between the full sample and restricted sample employee characteristics.)

The dependent variable in the analysis is the natural logarithm of the hourly wage. Employee respondents reported wages or salaries before taxes and other deductions in any frequency they preferred (hourly, daily, weekly, annually). They were also asked about additional variable pay from tips, commissions, bonuses, overtime, profit-sharing, productivity bonuses, or piecework. Hourly compensation was derived by dividing total pay by total reported hours. (Managers may be more likely to work unreported hours than other workers. Thus, hourly wages for this occupational group would be overestimated.)

Table 2 Wage effects of adopting a computer by occupation and education

Occupation	
Managers	.0704*
Professionals	.0437
Technical/trade	.0389***
Marketing/sales	-.0026
Clerical/administrative	.0118
Production, no trade	.0214
Education	
Advanced degree	.1760**
Bachelor's degree	.1031***
College or vocational training	.0289**
High school graduate	.0310
Less than high school graduate	.0146

Source: Workplace and Employee Survey, 1999 and 2000
*Statistically significant at * = p<.10; ** = p<.05; *** = p<.01.*
Note: The sample is restricted to employees who responded to the survey in both years and remained with the same employer in the same occupation.

run—although the premium is still positive and economically significant. Nevertheless, certain workers may earn higher than average returns. Evidence for such differential effects was sought by re-estimating the first-differenced model for workers by occupational group, educational group, and type of application used most frequently.

Six broad occupational groups were examined: managers, professionals, technical and skilled production workers, marketing and sales workers, clerical and administrative workers, and unskilled production workers with no trade or certification. Group samples were restricted to those who were in the same occupation in both years (Table 2). Even controlling for individual heterogeneity, managers earned a statistically significant 7.0% higher wages in the first year of computer use, compared with 3.9% for technical/trade workers. The remaining occupational groups, however, earned no statistically significant wage premium for adopting computers, and only the return to professionals using a computer was an economically significant 4.4%. These results coincide with expectations, since white-collar workers are likely to possess more problem-solving skills than other workers. If computers are a complement for high-skilled workers and a substitute for low-skilled workers, it makes sense that the adoption of computers would affect the wages of these groups differently. Estimations of the wage effect for the average worker obscure important differences between types of workers.

A second way to test for differential effects of computerization for particular types of workers is to estimate the models separately by education, dividing the sample into those with less than a high school diploma, only a high school diploma, college or vocational training, a bachelor's degree, or an advanced degree. Wage premiums are quite high for workers with an advanced degree (17.6%) or a bachelor's degree (10.3%), still positive for those with college or vocational training (2.9%), and not statistically different from zero for those with a high school diploma or less.

Another source of heterogeneity that may affect the returns to computer use stems from the different tasks performed. If technology complements a worker doing problem-solving tasks but substitutes for a worker doing repetitive tasks, then it may be important to look at more detailed questions of technology use. To do this, the adoption indicator was disaggregated into the primary software application used by the adopter (14 categories). In addition, two other types of technology—computer-aided tools (for example, industrial robots) and non-computer technologies (for example, cash registers and scanners)—were tested for (Table 3).

Table 3 The wage effect of adopting a specific application

	First-differenced model
Computer-aided technologies	-.0072
Other technologies	-.0034
Main application used (conditional on adopting a computer)	
Word processing	.0729***
Spreadsheet	.0189
Database	.0511**
Desktop publishing	.1996*
Management applications	.0246
Communications	.0694**
Programming	.0890
Specialized office	.0343*
Data analysis	.1091
Graphics	-.0152
Computer-assisted design	.0289
Computer-assisted engineering	.0171
Expert systems	.0866
Other	-.0173

Source: Workplace and Employee Survey, 1999 and 2000
*Statistically significant at * = p<.10; ** = p<.05; *** = p<.01.*
Note: The sample is restricted to employees who responded to the survey in both years and remained with the same employer.

The wage premium is largest for those adopting desktop publishing, data analysis, and programming (20%, 10.9%, and 8.9% respectively) compared with continued non-users. These applications tend to demand critical thinking or problem-solving skills. However, the variance for the coefficients in this model comes from individual workers who adopt a computer and this particular software. The number of workers in each group is quite small, resulting in large standard errors in most instances. Adopters who use word processing, database, communication, and specialized office applications earn significant, but smaller, wage premiums (7.3%, 5.1%, 6.9%, and 3.4% respectively). Thus while some of the estimates in the first-differenced model are quite noisy, some differences in the wage premium do appear to remain depending upon the primary application adopted. It does not seem that workers using technologies other than computers earn a wage premium for that usage. The three different groups of workers—by occupation, education, and type of software application used—seem to largely confirm that technology can affect workers differently.

Long-term results

One reason the traditional fixed-effects and flexible first-differenced models might yield small estimates of the return to computer use is that they measure the wage change within the first year of adopting or ceasing to use a computer. In order to estimate the return for maintaining computer use, the previous year's wage was used to try to capture the individual fixed effects. The average return to computer use for those who used computers in both periods was 8.3% in 2000 (Table 4). This large and significant return suggests that those with computer skills are earning higher wages than those who are first learning to use their new computers at an establishment. The return to adopting (4.2%) using the lagged wage approach was only slightly higher than that obtained using first-differences (3.8%), suggesting that lagged wages are good proxies for the individual fixed effects—at least for adopters.

Re-estimating the equation for the occupational and educational groups shows that most continued users earned a return to computer use. Even though workers in the marketing/sales and clerical/administrative occupations did not earn a return to adopting, workers in these occupations who continued their computer use earned economically significant returns of 10% and 8% respectively. Among the educational groups, continued users all earned an economically large return to computer use. High school graduates, one of the lower educational levels, earned one of the highest returns—10.6%. The coefficient on continued users in the advanced degree group was imprecise. These results suggest that previous fixed-effects models dramatically understate the 'true' returns to computer use, and in fact, only represent the much smaller average returns to adopting or ceasing to use a computer.

Not too surprisingly, the long-term returns are in most cases much larger than the short-term ones, since most workers will not immediately become more productive the instant a computer appears on their desk. Workers must learn to use a computer and incorporate it into their job.[5] In the first year of using a computer on the job, learning costs may be high for workers, especially those with no prior experience. These may be pecuniary costs of courses or on-the-job training, or opportunity costs of lost productivity

Table 4 The long-run wage effect of using a computer, value-added approach

	OLS	
	Maintainers	Adopters
All workers	**.0796*** **	**.0410*** **
Occupation		
Managers	.0664***	.0836**
Professionals	.0243	.0523
Technical/trade	.0862***	.0445***
Marketing/sales	.1043***	.0823
Clerical/administrative	.0771***	.0333
Production, no trade	.0563**	.0580*
Education		
Advanced degree	.0601	.1465**
Bachelor's degree	.0829***	.1018***
College or vocational training	.0831***	.0360***
High school graduate	.1008***	.0559***
Less than high school graduate	.0588***	.0175

Source: Workplace and Employee Survey, 1999 and 2000
*Statistically significant at * = p<.10; ** = p<.05; *** = p<.01.*
Note: The OLS model (using the 2000 sample) includes lagged wage, a constant, years of education, potential experience (and its square), parents or grandparents from a non-European country, different language at work than at home, part-time status, marital status, sex, sex interacted with marital status, union coverage, regional indicators, five occupational indicators, tenure with the establishment, the natural log of establishment size, the percentage of computer users in the establishment, and recent promotion. The other specifications exclude the occupational indicators.

while adapting their job to computer use. While some learning costs will be paid by the employer, workers may be expected to implicitly share them, since many of these applications add to their general transferable skills rather than firm-specific ones.

The data provide two ways to assess why returns are lower for adopters than for continued users. One is to compare the returns to adoption for those who received and did not receive computer training. Employees were asked if they participated in any on-the-job or classroom training on computer hardware or software related to their job and paid for by their employers. The 15% of adopters who received (and implicitly required) training would be expected to have lower wages while they paid their share of the training cost, resulting in lower returns in the presence of training. The second way is to compare the returns to adoption for workers with and without prior computer experience. Workers with prior computer experience may be able to reap higher productivity in their first year of computer use than those with no prior computer experience and thus earn a higher return.

Although results are imprecise for the interaction terms because of the small number of adopters with either prior experience or training,[6] the coefficients suggest that learning costs may affect the short-term returns to computer use (Table 5). A computer adopter not receiving training earns a return of around 4%, while one with training earns 3% (Model I). A worker without prior computer experience earns a return to adopting of 2.9%, while a worker with prior experience earns 5% in the year of adoption (Model II).

The theoretical model allows learning costs and the extent to which workers share them to vary across types of workers, showing that these variations can help explain the differential returns to computer adoption. For example, if low-skilled workers require more training than high-skilled workers to master a particular computer application, then it might take longer for any premium to be reflected in their wages. While separate estimations for the different occupational and educational subgroups are quite noisy, as the variance is derived from a one-year wage change, there is nevertheless some evidence that the sharing of these costs is especially high for particular groups of workers, although the pattern is not clearly related to skill level. The one significant result in the training interaction is for the marketing and sales occupations, which is consistent with the fairly large return to continued users for this group (Table 4). Other groups, such as professionals, clerical and administrative, and the highly educated incur economically large costs of training. While these are not all intuitive, the first-differencing method does not control for unobservable traits that might cause one worker to receive training in the second period and another worker not to receive the training. Thus, although the large negative effect on the interaction term for workers who hold a bachelor's or advanced degree is somewhat surprising (10.2% and 8.0% respectively), it is likely that many of these degree holders do not require formal training and that those who do are different in some important unobservable way. Alternatively, their training programs may be expensive because of the complexity of the applications they must master.

Table 5 Effects of training and previous computer experience on the computer adoption wage premium

	Model I		Model II	
Adopted in 2000	Overall	With training*	Overall	Prior experience*
All workers	**.0395*** **	**-.0101**	**.0289** **	**.0210**
Occupation				
Managers	.0630	.0544	.0451	.0590
Professionals	.0626	-.0663	.0189	.0673
Technical/trade	.0340**	.0322	.0379	.0026
Marketing/sales	.0459	-.2908**	-.0205	.0332
Clerical/administrative	.0305	-.0877	.0048	.0149
Production, no trade	.0178	.0541	.0048	.0433
Education				
Advanced degree	.1901***	-.0796	.1274	.1236
Bachelor's degree	.1210***	-.1018	.0834	.0339
College or vocational training	.0314**	-.0136	.0319**	-.0065
High school graduate	.0245	.0329	.0094	.0534
Less than high school graduate	.0129	.0156	.0152	-.0023

Source: Workplace and Employee Survey, 1999 and 2000
*Statistically significant at * = p<.10; ** = p<.05; *** = p<.01.*
Note: The sample is restricted to employees who responded to the survey in both years and remained with the same employer in the same occupation.

The size of the wage premium for those who do not receive formal training is larger for several of the low-skilled groups (for example, marketing/sales, clerical/administrative) than in the models that do not control for training. If workers were observed a few years after adopting computers, however, their wages might

be higher than those of similar workers who did not adopt a computer between 1999 and 2000. In fact, the effect should be larger than was measured here, since much of the learning costs are not reflected in formal training but in on-the-job experience using a computer.

Most groups also demonstrated a larger return for experienced adopters, shown by the positive return on the interaction, even though the estimates are imprecise. The exceptions are workers with college or vocational training or no high school degree and those in technical and trades occupations, which may indicate that the applications used by these workers tend to be firm-specific and that prior general computer skills are not readily transferable.

Conclusion

A naïve wage regression indicates that workers who used a computer earned 16.9% more in 2000 than those who did not use a computer. Controlling for unobserved worker heterogeneity using a changing characteristics model, the wage growth for the first year of computer use was a statistically significant 3.8%. This model allows the separate identification of the return to adopting a computer from the wage loss associated with ceasing to use a computer, which is not statistically different from zero.

This panel estimate, however, obscures important differences between types of workers and returns from using different computer applications. While technical workers, professionals and managers earn higher wages in the first year of computer use, other occupational groups, whose skills may be substitutes for computer technologies, earn no statistically significant return. Similarly, workers with a bachelor's or advanced degree earn 10% to 17% more when adopting a computer, while those with college or vocational training earn around 3% and those with a high school diploma or less earn no return. Returns to using different software applications vary markedly, suggesting a return to computerizable tasks that allow creative or cognitive skills to be better utilized. Workers who use other machinery or computer-controlled technology do not earn a return. Computers seem to be a complement to high-skilled workers performing problem-solving tasks and a substitute for low-skilled workers performing repetitive tasks.

Small but significant returns accrue for some workers in the first year of computer use. Using lagged wages as an alternative means of controlling for individual fixed effects, which provides an estimate of returns to computer use for those who used a computer both years, shows that the average worker who used a computer in 1999 and 2000 earned an 8.3% wage premium, more than double the return for the average adopter. In addition, continued users in most skill groups earned more than a 5% return to computer use in 2000.

The result that continued users earn more than adopters may represent greater productivity. The penalty associated with receiving training on a new computer suggests either that workers pay for training in terms of slower wage growth or that workers who receive training differ from those who do not receive training. Controlling for computer training increases wages for many of the low-skilled groups whose premiums were small or zero in previous models. In addition, computer adopters with prior computer experience earned more in the first year than those lacking experience.

Notes

1 See, for example, Bell (1996); Entorf, Gollac and Kramarz (1999); and Entorf and Kramarz (1997).

2 The simple correlation between adopting a computer and a recent promotion is 0.0317, while the correlation between ceasing to use a computer and promotion is -0.0054.

3 A random-effects specification and an establishment fixed-effects specification were also tried. According to results of the Hausman test, the null hypothesis that the individual effects are uncorrelated with the other regressors in the model could be rejected. The return to computer use controlling for establishment heterogeneity, but not worker heterogeneity, was 7.7%.

4 Some may be concerned with the large number of ceasers in the data. Dolton and Makepeace (2004) suggest two possible reasons why workers stop using a computer. One is that they may do so as they move up the promotion ladder. However, in Canada, the simple correlation between ceasing to use a computer and promotion is -0.0054, and this specification and those that follow controlled for promotion. The other reason is that ceasers are not very good at using a computer. A fixed-effects regression using only non-computer users in 1999 found a 3.9% return.

5 Bresnahan (1999) discusses the importance of re-organizing the workplace for effective use of computers.

6 Only 1.2% of the sample both adopted a computer and received some type of training.

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